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The ancient and modern conception of the atom

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DEPARTMENT OF PHILOSOPHY

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(CROWNED WITH THE MILDRED WILLIAMS BUCHAN PRIZE)

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INTRODUCTION

The Atomic Theory originated by Leucippus and developed by Democritus underwent modifications in many centuries and by many brilliant minds before reaching the twentieth century and becoming the basis of natural science. Aristotle, Epicurus, Lucretius, and Leibnitz handled the theory with the advantage of time over Democritus and Leucippus; and it is greatly to the credit of the latter thinkers that their speculations seem in most respects to stand the inspection of modern scientists as well as or better than those of their successors. That change was made by Leibnitz in the opinion of Lewes in his *History of Philosophy*:[1] "The Atomism of Democritus has not been sufficiently appreciated as a speculation. Leibnitz, many centuries afterwards, was led to a doctrine essentially similar; his celebrated *Monadologie* is but atomism with a psychological significance and new terminology." Aristotle certainly weakened the original doctrine by assuming lightness as an innate quality of atoms; just as Epicurus did in assuming that atoms were heavy and were perpetually falling downward through space. Democritus realized that there is no up or down in the world; and he stated that atoms with their original impetus moved in all directions, like motes in a sunbeam.

Therefore in discussing ancient and modern ideas of the atom little will be lost in not tracing the development of the theory. Democritus and Leucippus were the earliest and, in most respects, the keenest of the ancients; Epicurus and Aristotle contributed little. So the undertaking here will be to state as well as possible the speculations of Leucippus and Democritus, give a summary of modern atomic theories, and then compare the two.

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[1]Lewes, *History of Philosophy*, p. 102.

I. THE THEORY OF DEMOCRITUS AND LEUCIPPUS

There are some points on which Leucippus and Democritus do not agree exactly, but for the purpose of a brief survey a distinction between them is unnecessary. Diogenes Laertius writes of them as the atomists; Hegel in his *History of Philosophy* makes no distinction between them. Separating them is a distinct and sizeable problem since most secondary writers treat them together.

Knowledge of the original atomic system is largely secondhand, being gathered from accounts of it in the writings of Diogenes, Laertius, Theophrastus, and Aristotle. According to Burnet,[2] the only existing fragment which may be said with certainty to belong to Leucippus reads: "Naught happens for nothing, but all things from a ground and of necessity." While a large number of the fragments of Democritus have been accumulated, it is found that most of them are epigrams that serve little purpose in the construction of a philosophical system.

That the fragments leave much room for interpretation may be judged from Lewes' summary of the situation:[3] "Respecting his [Democritus's] philosophy there is some certain evidence; but it has been so variously interpreted and is in many parts so obscure that historians have been at a loss to give it its due position in relation to other systems. Reinhold, Brandis, Marback, and Herman view him as an Ionian; Buhle and Tennemann, as an Eleatic; Hegel as the successor of Heraclitus and predecessor of Anaxagoras; Ritter as a Sophist; and Zeller as the precursor of Anaxagoras. Of all these classifications that by Ritter seems to me to be the worst." Hegel reserves the honor of "worst" interpreter for Tennemann. He maintains[4] that while Democritus is an idealist of the highest type, Tennemann has represented him as a materialist recognizing the empirical world as the only reality. While a decision on the point does not seem essential to this paper, the latter view appears more reasonable. Burnet says in

[2]Burnet, *Greek Philosophy*, p. 99.
[3]Lewes, *History of Philosophy*, p. 98.
[4]Hegel, *History of Philosophy*, p. 305.

this connection[5] that Democritus rejects the special senses as a source of knowledge, but at the same time gives a purely mechanical explanation of true knowledge: "it is not thought but a kind of inner sense."

The specific characteristics assigned to the atom by Democritus and Leucippus will now be given. According to Democritus:[6] "By convention sweet is sweet, by convention bitter is bitter, by convention cold is cold, by convention hot is hot, by convention color is color. But in reality there are atoms and the void." Atoms and the void are the only realities. The void is an absolute vacuum—not air as held by the Pythagoreans. The void is essential for motion and for separation of the many.

Theophrastus says of Leucippus:[7] "He began by assuming an unlimited number of elements, the atoms, which were always in motion. And he supposed them to have an unlimited variety of forms . . ." Aristotle supports this[8] and adds that the atoms are invisible because of their smallness; "coming together they cause coming-into-being; being separated they cause passing-away." Thus the atoms are infinite in number and in form, but all are below the limit of the minimum visible. Motion is imparted by a superior force and is innate in each atom; no atom coming to rest unless stopped by collision with another.

Weight is not a primary quality of the atom,[9] it is possessed by the atom only after it has become involved in a vortex exercising centrifugal force.

These are the qualities of the atom and the void, from which the atomists derive their philosophical system. The world, the soul, knowledge, everything is explained by the action of these indivisible units of matter. All objects of our senses are combinations of them. Driven by their original motion, atoms striking against one another set up vortices; in these whirlpools the larger and more elongated atoms settle toward the center, while smooth-

[5]Burnet, *Greek Philosophy,* p. 195.
[6]Bakewell, *Source Book in Ancient Philosophy,* p. 60.
[7]*Ibid,* p. 57.
[8]*Ibid,* p. 58.
[9]Burnet, *Greek Philosophy,* p. 97.

er and smaller ones tend to be forced to the edges. This separation is the origin of earth, air, fire, and water.

The soul is conceived as being composed of round, smooth atoms which are perfectly mobile and penetrate without effort to all parts of the body. According to Aristotle,[10] Democritus held "that the soul and reason were the same thing, and that this belonged to the class of primary and indivisible bodies, and had the capacity of motion because of the small number of its parts and because of its shape. Now the most mobile shape is the spherical, and such is the shape of reason and of fire."

Knowledge is of two kinds: trueborn and bastard. This division, says Burnet,[11] has much in common with the modern distinction between primary and secondary faculties. But both forms are given a mechanical, atomical explanation. Bastard knowledge is that which comes through the special senses: taste, touch, sight, hearing and smelling. Purely conventional, says Democritus of this form; it is the blurred image of an object which is given off in streams of atoms and reaches the mind through the sense passages. A higher form of knowledge, the highest of which man is capable, comes directly to the atoms of the soul from atoms outside the body without coming through the sense passages. Knowledge of existence, mathematical conception of the infinitely small, and such concepts come through this channel.

II. MODERN SCIENTIFIC THEORY OF THE ATOM

Investigation of the atom began with chemical determination of atomic weights. Relative weights were obtained by an application of Avogadro's Law. Hydrogen was found to be the lightest atom. At first it was thought advisable to take hydrogen as a unit for weighing other atoms; but it proved more practicable to take the weight of oxygen at 16 as an arbitrary standard. Hydrogen in that scale has the fractional weight 1.008, but most atomic weights thus become whole numbers.

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[10]Bakewell, *Source Book in Ancient Philosophy,* p. 66.
[11]Burnet, *Greek Philosophy,* p. 197.

After the elements were arranged in order of atomic weight, it was observed that at certain intervals there were elements having similar chemical properties; for instance, the 3rd, 11th, and 19th might be characterized by alkalinity; another group at regular intervals along the scale, by acidity, and so on. While the correspondence was of varying degrees of exactness, there appeared to be eight well-defined groups; when the elements were rearranged in an order determined by their properties the list was called the periodic table. This list begins with hydrogen, one, and runs through uranium, ninety-two. (The number of its position counting from hydrogen up is called the atomic number of an element.) Peculiarities in this table soon suggested to physicists and chemists that there might be a fundamental unit from which all the elements were built up. One of these peculiarities was the fact that many of the elements had numbers which were integers, and the atomic weight corresponded in most instances to the atomic number. Further significance was given the table by the discovery of several new elements with properties which had already been predicted from blank places in the periodic table.

The search for the common unit, which followed, proceeded along three different paths. First was the analysis of light by the spectrum; second, the study of X-rays; and third, the study of radio-activity phenomena. Each produced valuable results. Spectrum analysis gave information about the outside electrons in simple atoms like hydrogen and helium; the X-ray helped in the study of inner groups of electrons around complex atoms; radio-activity proved the only means of studying the nucleus of complex atoms.

According to Bertrand Russell,[12] the form of the hydrogen atom and the mathematics involved are now completely understood. The hydrogen atom consists of only two parts: a simple nucleus, which is sometimes called a proton, and a single electron revolving about the nucleus at a relatively great distance. The proton carries a positive charge of electricity, the smallest charge

[12]Russell, *The A B C of Atoms,* introduction.

that can exist; the electron carries the minimum charge of negative electricity. The proton is approximately 1,800 times as heavy as the little planet revolving about it—so much heavier that in calculations of mass of atoms the electron's mass is ignored.

Experiments to determine the size of electrons and the speed at which they travel have been very successful, the results in one field bearing out the findings in another. C. R. Wilson photographed the tracks of electrons through a rarified water vapor, this being possible on account of the condensed droplets of moisture left in the wake of the electron. When an electron came near an atom of the gas through which it was travelling, it was deflected and by measuring the mass of the atom and then the deflection, the mass of the electron was calculated.

The charge on the electron was obtained by somewhat similar methods; Rutherford experimenting with alpha particles from radium, and Professor Millikan capturing ions on mercury drops got practically the same figures for the charge.

The diameter of the electron, according to Mr. Russell, is such that twenty million million would be required to make up the length of one centimeter. As its size is inconceivably small, so the rapidity with which it travels in its minute orbit is inconceivably great. At a speed of 1,400 miles per second it makes its circle seven thousand million times in a millionth part of a second.[13] The size of the nucleus, or proton, seems to be the same as that of the electron although its mass is 1,800 times as great.

The distance of the electron from the nucleus varies. This fact is the explanation of radiation according to the Danish physicist Niels Bohr whose theories have been fairly well established. The greater the distance between the two the greater the energy in the system. If the electron drops from a certain orbit into another nearer the proton, energy is liberated in the form of a wave in the ether; if energy is absorbed by the system, the electron moves into a more distant orbit.

This theory of Bohr's was formulated as an explanation of the relation between lines in the hydrogen spectrum. Light from a

[13]Russell, *The A B C of Atoms*, p. 28.

glowing gas if passed through a spectrum will show a series of lines at varying distances from one another. These lines are, of course, dependent on the variety of wave lengths in the light, just as the colors in a "band-spectrum" are. Before Bohr pronounced his theory, it had been discovered that there was a peculiar mathematical relation between the distances of the lines in the hydrogen spectrum; but the relation was not understood. The relation was based on a certain fundamental wave number called Rydberg's consonant which was found always to exist in line spectra. ("Wave number" means simply the number of waves in a centimeter. That is, if a certain kind of light has a wave length of 100,000th of a centimeter, its wave number is 100,000.) It was observed that if this number, which is about 109,700 waves per centimeter, is taken as one term, and a series of terms obtained from it by dividing it by the square numbers 4, 9, 16, 25, and so on, then the lines in the hydrogen spectrum will have wave numbers corresponding to the differences obtained by subtracting each term from the next larger. This statement of fact will be made clearer by the explanation of the relation.

Bohr's fundamental assumption is that there are definite orbits to which an electron is limited. In every case there exists a minimum—which cannot be explained. Then the next larger orbit has a radius four times as great, the next nine times as great, and so on, multiplying by square numbers, the maximum being when the electrons get so far away that the attraction of the positive and negative electricity is not sufficient to prevent their being pulled away by the attraction of other systems. This maximum varies, of course, with the density of the substance in which the atom is present. The greatest distance between electron and proton is observed in the atoms of certain nebulae which are more tenuous than the most perfect vacuum physicists have yet produced. But, to return to wave emission according to Bohr's theory, when an electron passes from the orbit with radius four to the minimum circle, the wave given off has the wave number which is ¾ of Rydberg's consonant; and when it passes from the orbit with radius nine to the minimum orbit it produces the wave with number 8/9 of the consonant.

Thus when a gas is glowing and giving off light its atoms are losing energy. The electrons of all the atoms are falling into smaller orbits; but some are going from orbit of radius nine to orbit of radius one, some from orbit of radius sixteen to orbit of radius nine, and so on. All of those electrons which are making the same sized drop are causing the same wave length, each of the waves having its own spectrum line. The theory that energy is given off by an atom only in certain definite quantities is called the "quantum theory." Edwin E. Slosson says of it:[14] "The quantum theory is quite as important as the relativity theory and even more disconcerting to our ordinary ideas." The disconcerting thing about it is that energy is dissipated through radiation not continuously but in minimum quantities. Also the fact that in going from one orbit to another the electron seems to pass over the intervening space without any lapse of time. Russell commenting on this fact says:[15] "When an electron jumps from one orbit to another, this is supposed to happen instantaneously, not merely in a short time. It is supposed that for a time it is moving in one orbit, and then instantaneously it is moving in the other, without having passed over the intermediate space. . . . This process by which an electron passes from one orbit to another is at present quite unintelligible, and to all appearances quite contrary to everything hitherto learned about the nature of physical occurrences." There is at present no explanation, he continues, but speculation might lead to the startling suggestion that there isn't any intervening space, that space is not continuous; or that time is not continuous, but a finite number of jerks with nothing between them. Slosson refers to the quantum hypothesis as the "jerk theory."

The complex atoms will now be briefly discussed. As was shown by the figures given about the hydrogen atom, the distance between the nucleus of an atom and its planetary electrons is very great compared with the size of the bodies. All atoms have the same loose structure, a tight little nucleus and electrons at a great distance. If the scale of the hydrogen atom were

[14]Slosson, *Chats on Science*, p. 248.
[15]Russell, *The A B C of Atoms*, p. 54.

increased sufficiently to make the proton and electron as large as pin heads, the two would be a hundred yards apart.[16]

Hydrogen is the simplest of the atoms but all have the same general make-up, nucleus and electrons. If there are many of these electrons they are arranged in several rings (at least that is the theory most in favor with physicists at present) with several electrons in each ring. The rings are not always in the same plane. Naturally, the farther an electron is from its nucleus the easier it may be dislodged. The outside electrons shifting orbits or being dislodged completely their system cause heat, light, and electric phenomena. The inner electrons in their jumps from orbit to orbit cause vibrations in the ether of very great frequency, and these short waves produce X-rays.

The most interesting phenomenon connected with internal changes of the atom is radio-activity and this is a change in the nucleus itself. The structure of nuclei is not thoroughly understood yet, but there is nevertheless much that physicists now say of it with a considerable degree of certainty.

First, it is believed that even the most complex nuclei are made up of electrons and hydrogen nuclei, or protons. It is the nucleus of an atom that determines the properties of an element; its atomic number and weight. Its atomic weight is believed to be the total number of protons in the nucleus; and the atomic number is the number of protons above the number of electrons, that is the net positive charge. This net charge is usually about half of the total number of protons. For instance, suppose neon had atomic number 10 and atomic weight 20. It would then be assumed that there were 20 protons in its nucleus and 10 electrons, the electrons balancing off the charge of ten protons and leaving net positive charge of 10, the atomic number. The weight would be 20, the total number of protons. The weight of the electrons is disregarded as not appreciably affecting the total weight.

The fact that atomic weights are not always whole numbers as they should be if the atom has a definite number of units brings up the interesting question of isotropes. To explain isotropes

[16]Kimball, *Physics*, p. 558.

the neon illustration will be taken up again. Neon has atomic number 10. When the element is separated and tested for its atomic weight, the result is 20.2, instead of 20 as it should be. Recent research has indicated that the element weighed is made up of two isotropes with atomic weights 20 and 22 which are mixed in such a proportion as to give the average 20.2. The first isotrope, then, has 20 protons and 10 electrons, leaving atomic number 10. The second has 22 protons and 12 electrons, leaving the same atomic number, 10. Thus they have the same atomic number but different atomic weights. As it is found that the number is more important than the weight in determining properties, the two are called, not different elements as they well might be called, but isotropes of the same element. It is now believed that elements having atomic weights which are not whole numbers are made up of various isotropes which do have whole numbers.

The causes of radio-activity are not known, but much has been learned about the circumstances and results of the breaking down of the atoms concerned. The element at the top of the list as regards atomic number is uranium, number 92. As are all the half dozen heaviest elements at the head of the table, uranium is breaking down and changing into other elements. Of the time involved in the process Russell says:[17] "It is customary to measure the rapidity of disintegration by the length of time that it takes half of a given collection of atoms to die. This period varies enormously from one substance to another. Uranium, which is only slightly radio-active, takes 4,500 million years, in its most stable form, for half its atoms to decay. The first product of their disintegration is a substance of which half decays in just under 24 days; this breaks down into a substance for which the period is less than a minute and a quarter; the next substance has an uncertain period, estimated at two million years; at this stage two different substances may be formed, one of which in turn becomes radium, of which the period is 1,580 years, while the other becomes protoactinium of which the period is 12,000 years, the next product being actinium." The end of both series is a

[17]Russell, *The A B C of Atoms*, p. 111.

form of lead, which, so far as is known is not radio-active at all.

Thus all the more complicated structures are breaking down and losing energy, becoming simpler atoms. Possibly there were at one time elements more complex than uranium or radium; if so their equilibrium must have been very unstable and their life very short unless they existed in conditions very different from those observable on the earth. To quote Russell again:[18] "We see complex atoms breaking up, and it is natural to suppose that there are or have been circumstances under which they are put together out of simpler atoms. But no trace of any such circumstances has been discovered. In this respect as in some others, the universe *seems* like a clock running down, with no mechanism for winding it up again." In this running down process the radio-active substance may lose matter and energy from its nucleus in two different ways: by streams of electrons, called Beta-rays; and stream of helium nuclei, called Alpha-rays—in some cases both are thrown off simultaneously. The electrons released from radio-active nuclei move with the greatest velocity matter is known to attain. Their speed approaches very near to the theoretical limit, the velocity of light, 186,000 miles per second. The much more massive helium nuclei have a speed about one-tenth as great.

At this point the status of the helium nucleus should be established. As was just remarked, the Alpha-particles thrown off by radio-active elements are identical with the helium atom. It is very stable, and has never been broken down any more than have protons and electrons. While the possibility of this being a third indivisible constituent of matter is admitted, it is generally supposed that it is composed of four protons and two electrons in some very stable arrangement. This conclusion is drawn from the facts that its mass is almost precisely four times that of the hydrogen nucleus, or proton, and that its positive charge, or atomic number, is just twice as great.

From what has been said about the theory of nuclear structure, the results of Alpha-ray and Beta-ray emission can be foreseen. If an electron is lost from the nucleus, the atom has no appreciable change in weight, but, since that electron was neutraliz-

[18]Russell, *The A B C of Atoms*, p. 111 ff.

ing the electric charge of one proton, the net charge, or atomic number, is raised one. When one helium nucleus is thrown off by an Alpha-ray, the atom has lost four protons and two electrons; this lowers the atomic weight four, but lowers the atomic number only two since two electrons went with the four protons.

Radio-activity was for many years the only case of transmutation of elements known. Recently, however, Rutherford[19] has succeeded in dislodging hydrogen atoms from nitrogen by a bombardment of Alpha particles, and the composite character of the atom is completely established. The elements are thus shown to differ not in the quality of their substance, but in the amount of energy and arrangement of protons and electrons in their atoms.

III. COMPARISONS

Considerable respect for the speculations of Leucippus and Democritus is indicated by the fact that F. H. Loring's book *Atomic Theories,* published in 1921, and purporting to be a statement of the modern conception of atomic structure, opens its first chapter with six fragments from Democritus and a statement by Professor Millikan[20] that "these principals [those of Democritus] with a few modifications and omissions might almost pass muster today."

Before going to the business of paralleling the various characteristics ascribed to the atom by the ancients with those it is now supposed to have, it may be worth while to comment on Democritus's conception of the void. It has already been noted that he insisted on a pure vacuum as an absolute reality the opposite of the atom, the *plenum.* Very many of the ancient Greeks were unable to conceive of this *non-being.* Parmenides and other Eleatics insisted that nothing might exist of which the mind could form no idea; *non-being* therefore, was unthinkable and nonexistent. Democritus argued that the void was as essential as the *plenum* to an account of motion and the "many." One of the most important question before the modern physicist has been the ether. A knowledge of its properties seems necessary to an under-

[19] Kimball, *Physics,* p. 562.
[20] Loring, *Atomic Theories,* p. 1.

standing of radiation. Very accurate observations have been made in an effort to determine whether it offers any resistance to the motion of the earth. None has been found; and it seems that Democritus's void is no more empty than the luminiferous ether now hypothecated as the medium of light wave transmission.

The principal achievement of Leucippus and Democritus was in substituting the atom for the *homoemeriae* of Anaxagoras. The latter philosopher held that the universe consisted of an infinite number of qualitatively different particles. Any substance—wood or clay for instance—might be divided to its smallest part and the substance would still be the same—wood or clay. This plurality of elements led Anaxagoras into extremely difficult situations, such as the necessity of explaining how flesh and blood come to be produced from food and drink, or ashes and smoke revolved from fire. His explanation was that every substance had in itself, to a certain degree, all other substances, and its properties were determined from the one which predominated. This awkward situation was avoided by the atomists when they assumed that atoms had no properties in themselves but by their combinations and configurations gave rise to different substances. All generation was external; a body was formed by a combination of atoms, and dissolved with the disassociation of the atoms. In this regard science has clearly borne Democritus out to the letter: water is ultimately not water, but oxygen and hydrogen, and these are ultimately proton and electron—the "atoms" of Democritus, possessing none of the qualities of oxygen or water.

Burnet considers it one of the best examples of the true scientific sense of the early atomists that they ascribed no innate quality of weight to the atom. Its weight came only after it became associated with other atoms in the regular motion of the vortex. Science at an early stage of its development recognized that Democritus was correct in this respect, and that weight could not be listed among primary qualities along with form, mass, and extension. As has already been mentioned, Aristotle and Epicurus were not as acute as Democritus on this score;

the first ascribed absolute lightness to the atom; and the second absolute weight.

As to the number and size of the atoms no fault is to be found with Democritus' statements. He says that all atoms are so small that they are invisible. Whether we use electrons, atoms, or molecules to correspond to his term, our unit is also still below the limit of visibility. He says the number is infinite; certainly no limit can now be set.

Now comes the problem of divisibility of units, a problem that thousands have approached since Zeno's lifetime, and that all have left with a sense of dissatisfaction. Democritus was certainly interested in Zeno's puzzle. Fragment number 155 is quoted by Burnet:[21] "If a cone is cut by a plane parallel to its base, what are you to think of the surfaces of the two sections? Are they equal or unequal? If they are unequal, they will make the cone uneven; for it will have many step-like incisions and roughnesses. If they are equal, then the sections will be equal and the cone will have the properties of a cylinder, which is composed of equal, not unequal, circles. Which is most absurd?" No answer to the problem is given at that point, but Leucippus speaks to the point in another place. He says[22] of the atoms that they are mathematically not indivisible, but are physically indivisible, since there is no empty space in them. Of course this paradox has never been solved by science; but Democritus' statement that the atom is physically indivisible checks with the modern notion of the electron and proton according to Russell. Russell says:[23] "With electrons and hydrogen nuclei, so far as our present knowledge extends, the possibility of dividing matter up into bits comes to an end. No reason exists for supposing that these themselves have a structure, and are composed of still smaller bits. We do not know, of course, that reasons may not be found later for subdividing electrons and hydrogen nuclei; we only know that so far nothing prevents us from treating them as ultimate. It is difficult to know whether to be more astonished

[21] Burnet, *Greek Philosophy*, p. 199.
[22] *Ibid*, p. 97.
[23] Russell, *The A B C of Atoms*, p. 2 ff.

at the smallness of these units, or at the fact that there are units, since we might have expected matter to be divisible *ad infinitum*." Thus, at the present time, credit must be given the atomists for close reasoning or keen conjecturing in stating belief in a physically indivisible unit of matter. That the "atom" of the present day has been broken up should not be allowed to detract from the accuracy attributed to Democritus's observation; for it must be remembered that "atom" had not the definite significance that it has now, but simply meant "indivisible." His "atom" should rightly be compared with the electron and proton of today.

Thus far everything has gone to bear out Professor Millikan in his opinion that Democritus' philosophical theories are remarkable. The early atomists, it seems, were justified in calling the void absolute, in calling weight a secondary quality of matter, and in naming as the unit of matter an invisible, indivisible, but finite particle called the atom.

There now remains what looks like the weakest point in Democritus' system. How did he account for the multiplicity of existing substances? He does it by assuming that there is an infinite variety of sizes and shapes of atoms, and that when they are separated into kinds—the round with the round and so on—such substances as earth, fire, and water are produced. The force required for separation is exercised in the vortices formed by collisions of moving atoms. But it seems that if separation is all that is required of force, then Democritus's atoms must have positive qualities like the *homoemeriae* of Anaxagoras; this is the weakness of the system. Their units of matter were the same in quality—neutral—yet to produce a variety of substances the only force they assumed was motion and the only action separation. The modern theory has matter reduced to two simple elements, but it requires of energy considerably more than separation. True the function of force as a determining principle may not be clearly *understood*, but it is certainly recognized and appreciated. Electrical and kinetic energy in stupendous amounts are involved in the complicated arrangements of electrons and protons that go to make elements of distinct properties. The immanent dependence of matter on energy is indicated by Einstein's revelations in regard to relativity, which show that the mass of a body increases with its velocity. This dependence, insignificant in most calculations, becomes vital in the study of velocities of the magnitude of Beta-rays; for instance, an electron released in radio-activity from its atomic nucleus moves off at a speed of about 184,000 miles per second, a velocity which increases the mass and kinetic energy of the particle by about six hundred per cent. Dependence of mass on energy is also used to explain a variation of the weight of the proton. In the hydrogen atom it weighs 1.008; when it goes into combination with other protons to make up helium or more complicated atoms, it loses energy for some reason and its weight drops to exactly unity.

Thus, whereas Democritus in accounting for *becoming* failed to provide for any principle outside of the atom and the void, and original motion, science finds energy playing a major role in every atom. On every minimum particle of matter there is a charge of electricity acting with a force of attraction or repulsion on every other charge of electricity—likes repulsing, opposites attracting. Democritus considered the motion and matter inherent in the atom sufficient to explain the whole universe and its operation. In the light of modern discoveries it would seem that Democritus—at least in this respect—was not so near in the way of truth as Heraclitus, who said that strife between opposites was at the root of all becoming, or as Empedocles, who had as a creative principle the opposition of love and hate.

BIBLIOGRAPHY

Bakewell, C. M., *Source Book in Ancient Philosophy,* New York, 1907.

Burnet, John, *Greek Philosophy,* London, 1914.

Hegel, G. W. F., *Lectures on the History of Philosophy,* London, 1892. 3 vols.

Lewes, George Henry, *The History of Philosophy from Thales to Comte,* London, 1880. 2 vols.

Loring, F. H., *Atomic Theories,* New York, 1921.

Russel, Bertrand, *The A B C of Atoms,* New York, 1924.

Kimball, A. L., *College Physics,* 3d. ed., revised, New York, 1924.